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Editorial

Dead zone dilemma

Many of the habitats essential to our fisheries resources have developed problems with low dissolved oxygen (DO). As DO declines, it immediately becomes an acute problem very few species can ignore.

What is the problem with a dead zone?

Coastal areas low in DO are typically devoid of mobile fauna that sense troubled waters and flee, which led to the term 'dead zone'. In general by the time DO reaches 2–3 mg/L, mobile fauna have fled. Sessile fauna unable to escape are stressed and often die when low DO events extend through time. This highlights the primary problem – insufficient oxygen disrupts the normal day-to-day transactions within an ecosystem. The formation of a dead zone leads to a set of faunal responses analogous to humans preparing for an impending hurricane. Those that can, flee; those that can't, go into survival mode. In either case, flight or stay, there are consequences that range from minor (having to leave forage or nursery grounds, or suppressed immune response) to major (increased predation from forced exposure and migration, or death from lack of oxygen).

The most pronounced effect of dead zones is the disruption of energy flows in unwelcome ways away from upper trophic levels. In the absence of upper trophic levels (mostly mobile fauna that fled), energy that previously was used to sustain complex food webs is diverted to lower trophic levels (microbes). This energy shunt to microbes leads to reduced trophic complexity and ecosystem services that would otherwise be capable of supporting a higher biodiversity and production of valued top predators. A conservative global estimate of biomass lost to coastal dead zones annually is over 9,000,000 metric tons wet weight of organisms. This is a lot of potential food for higher trophic levels, including humans, basically eaten by microbes (Díaz and Rosenberg, 2008).

Where and why do dead zones form?

There are places on earth that have developed low DO over the eons through natural processes (Helly and Levin, 2004). These areas, primarily oceanic oxygen minimum zones (OMZs), have relatively stable low DO and consequently a fauna highly adapted to living under low DO conditions (Levin, 2003). The interaction of winds, upwelling, and currents can also lead to dead zones close to shore, which are seasonal or episodic and often produce mass mortality.

The development of hypoxia in coastal systems is an unintended consequence of an expanding human population and its activities. Dead zones have become a common reoccurring problem within the last 50 years. While the basic biological and physical processes that create low DO conditions are natural, the formation of recurring dead zones in coastal areas is completely unnatural. The agricultural revolution of the 20th century has fed our ever-expanding population and inadvertently fueled an eutrophication revolution (persistent over-production of organic matter). It is the decomposition of this excess organic matter that has led to expansion of dead zones.

The global use of industrially produced fertilizers and burning of fossil fuels have interacted with and seriously altered the Nitrogen Cycle to the point that now the global Nitrogen Cycle is just as out of balance as the global Carbon Cycle. It has taken >100 years for humans to disrupt the Carbon Cycle but <50 years to disrupt the Nitrogen Cycle. The delivery of reactive nitrogen (rN) and terrestrial phosphorus (P) to the oceans has increased threefold from pre-industrial agricultural times. Increased rN and P can enhance phytoplankton growth in the coastal zone, but P is mainly an issue in freshwater plumes and low salinity areas like the Baltic Sea, the largest of all dead zones. The addition of rN from the atmosphere is a combination of the much accelerated burning of fossil fuels and the volatilization of ammonia from fertilizers and manure. The enhancement of rN in coastal waters is considered the major determinant of increasing algal growth. The unintended consequence of increasing the fertility of coastal seas has been the acceleration in the rates of natural processes that consume oxygen and lead to the formation, spreading, and worsening of dead zones.

How to reduce the number of dead zones?

The primary solution is straightforward; drastically reduce the amount of rN and P that reaches the sea. Implementing the solution is difficult, will not be straightforward, but is doable. Prior to the 1950s the main factors leading to the formation of dead zones were sewage and industrial discharges. Through management that reduced organic matter and nutrient loadings from these point sources, improvements in DO and elimination of dead zones in many systems were observed up to the 1980s. Between the 1970s and 1980s, nonpoint sources (runoff and air deposition) became the main factor causing dead zones and today continue to fuel their expanding numbers. We need to put excess rN and P entering marine systems into the same context as CO_2 entering the atmosphere. We need to implement ways to reduce inputs to the environment, and to sequester or recycle what is used. Our degradation of watershed and coastal ecosystems has also contributed to the problem. Wetlands capture and remove nutrients before they make their way to the coastal ocean. Loss of wetlands and channeling of rivers around them means more nutrients enter

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coastal oceans. This set of situations has put ecosystems in disorder, and it will take a long time to regain the balance. So we need to act forcefully and now.

There is growing evidence that delays in reducing rN and P will be increasingly costly to both humans and ecosystems. Over the years, the accumulation of organic matter and nutrients within ecosystems has set the stage for regime shifts that led to more hypoxia for a given input of additional nutrients. Once past this tipping point, greater reductions in nutrients will be required to control dead zone formation and reduce their size (Turner et al., 2008).

The good news is that nutrient reduction does lead to elimination of dead zones and recovery of ecosystem services. But it has to be a substantial reduction in the total pool of nutrients entering a system. This is the problem delaying reduction of Chesapeake Bay's (USA) dead zone. While controllable sources of rN and P have been reduced, the overall loadings to the Bay from a growing population have more than offset managed reductions. The best support for positive results from reducing nutrients comes from the northwest continental shelf of the Black Sea where the elimination of a huge dead zone (40,000 km^2) within three years and return of ecosystem services followed a three- to fourfold reduction in nutrient loads from contributing watersheds. Unfortunately, the reductions were the result of economic collapse following the dissolution of the Soviet Union—a course of action that is not desirable for control of dead zones. As the economy of the region improves, the recurrence of the dead zone is imminent along with reversals in ecosystem improvements.

Adoption of technologies and land use practices that reduce flows of nutrients to the coasts are needed in areas with dead zones and especially in areas not yet hypoxic. Localized action (field by field, farm by farm) is needed to reduce the escape of nutrients from land, but this local action needs to be taken at national and international scales to be effective. We caution that gains in reducing dead zones locally should not be offset by creation of dead zones elsewhere around the globe. Exporting the problem of excess nutrient use by importing agricultural products is not a viable solution to reducing dead zones globally.

What does the future hold for dead zones?

This will depend on a combination of population control, improved land use, reductions in Nitrogen and Phosphorus, and climate change, and their complex interactions (Rabalais et al., 2009). By the 1990s it became clear that climate change will drive coastal hypoxia to new levels of ecosystem impacts. Higher temperatures will reduce the amount of oxygen that seawater can hold, and will accelerate organism metabolism and thus demand for oxygen. Temperature increases combined with increased precipitation will increase density stratification of surface water and reduce mixing of oxygen so it does not get to where it is most needed. This may be partially off set by stormier weather, but will the storms occur at the right time in the needed places?

Climate change will be a double disaster for coastal ecosystems with factors forming dead zones originating on land and in the sea. From land, the combined effects of climate changes plus agriculture and land use will certainly be disastrous for coastal systems as fertilizer use and runoff increase. Consider the diversion of agricultural production for biofuels. In mandating the use of ethanol, now fueled primarily by corn kernels, little consideration was given to the increased runoff of nutrients from increased fertilizer use and expansion of row crops resulting in more erosion. The rush to produce more corn by returning more land to agricultural production has reversed declining trends in fertilizer use in both the USA and Europe. From sea, the greatest threat will be from increased temperatures, and changing winds and currents that will alter the strength of upwelling, driving lower oxygen waters closer to shore. OMZs are now expanding to encompass shallower depths, and as they approach continental shelves, mass mortalities of bottom-dwelling organisms are likely. The recent development of a dead zone, with mass mortality, on the inner continental shelf off Oregon and Washington (USA) was associated with changes in wind and circulation patterns away from long-term patterns. Similar phenomena threaten more of the eastern Pacific and southeastern Atlantic coastal zones, where oxygen levels are already precariously low.

In summary

Lack of management of nonpoint nutrient loadings is the main factor fueling the expanding number of dead zones. The challenge will be to reduce nutrient loads reaching our coastal systems by increasing the efficiency of agriculture and restoring landscapes. We must encourage countries switching to or expanding industrial-scale agriculture (South America, Africa, and Asia) to think ahead and avoid future costs and consequences to fisheries and humans, and more importantly persuade through leadership in our own developed countries where we have failed to act responsibly (USA, Europe, and Japan).

As with climate change and increasing atmospheric CO_2, the time to act to reduce excess nitrogen and phosphorus is today, if not sooner. More people require more food, fuel, and fiber. So the problems with oxygen in our coastal seas will not solve themselves. It all adds up to more CO_2, more nitrogen, more phosphorus, and fewer renewable resources on an Earth with a global ecosystem and a global economy. Forceful action is long overdue.

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